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CONVERSION OF BIOMASS RESOURCE TO USEFUL FORMS OF ENERGY AND OTHER PRODUCTS
TASK 4

University of Arkansas
Fayetteville, AR

Steven Jennings
Chemical Engineering
Spring 2007

Gasification is the process of burning an organic feed at a very high temperature in a low oxygen system. This process produces hydrogen, carbon monoxide, and some methane. These gases can go on to be treated a number of ways, but for the purpose of this project, we used combustion in a steam boiler. The steam is then run through a turbine to make electricity. However, this alone isn't economical so we would use remaining heat energy for drying the feed and at a local plant. The combusted gases can contain SO_x and NO_x so a scrubber had to be designed and added on the combusted gas outlet.

For the proper design of the different parts, a detailed mass and energy balance had to be formulated. For this, I first had to obtain the composition of manure so as to see the amount of carbon, nitrogen, and sulfur present. Using this data along with information on the composition of the gas burned without oxygen, the heating value of the manure could be calculated. I used a Chemcad reactor to model the boiler and then compared that to the heating value of the components of the gas. Using this and applying applicable efficiencies, the electricity output could be deduced and used to see what kind of scale would be economical. This led to deciding upon the feed rate of manure from 8000 dairy cattle.

Using the feed rate, I designed the plant scale gasifier. I found a design similar to a tunnel kiln would work well. It was a fire brick tunnel with a slanted floor that the feed slowly rolled down as it entered the gasifier. Based on the desired temperature to make the proper product gases and not pyrolysis products or melt the ash, I found how long the floor would need to be in order to fully gasify the feed. This led to another problem of how to keep the gasifier at the proper temperature. By simply feeding the product gases in a channel under the feed area, the required heat could not be delivered due to the properties of the fire brick. To fix this, we had to feed in enough oxygen to partially combust the gases. I used Chemcad once again to find how much of the product gas had to be combusted to provide the necessary heat. It came out to be 40% stochiometric oxygen. I also had to design a way to deliver the air. I found that feeding the air up through the bottom allowed for better contact with the feed. Using this knowledge, I designed a floor with holes evenly spaced down the first part of the floor, and small baffles that jutted out over the holes to prevent clogging with feed solids. These baffles were still at a slope so that feed didn't stop and build up at the start of the baffle. The solid waste then fell out the bottom onto an auger that fed the charr out which could be used for a number of things based on the original feed. The gas products went on to the boiler and turbine which I designed based on the heat created and how much steam would be made.

For the bench scale unit, the design was similar, but was batch feed and all the gases were instantly combusted. All the heat created went to gasifying the feed. Due to this combustion and the gases being created before the combustion, there was a danger of explosion. Another team member and I designed blast shields to protect against this. Using plywood and 2 x 4's, we built four walls to surround the gasification unit. We made proper measurements and cuts to insert the pipes through so the shields could be screwed together to seal in the explosion and push it upward.

When the final unit had been built, it was started with propane and fed with manure and tree trimmings. After the desired temperature had been met, we turned off the propane, and were able to keep the temperature constant using just the heat from combustion of the product gases. This successful run of the bench scale unit gave supportive evidence that the plant scale unit could be made to work with a few adjustments for the small differences in design.

This design used team work and the lessons learned from Chemical Engineering course. I used my engineering knowledge to create full mass and energy balance tables for the bench scale and plant scale. It also allowed me to be able to design how to treat the products. The most important application of my knowledge was using reasoning to design out a practical gasifier, and how to find solutions for any problems that arose with this design.

CONVERSION OF BIOMASS RESOURCE TO USEFUL FORMS OF ENERGY AND OTHER PRODUCTS

WERC 2007

TASK 4

UNIVERSITY OF ARKANSAS

CONVERSION OF BIOMASS RESOURCE TO USEFUL FORMS OF ENERGY AND OTHER PRODUCTS

TASK 4

University of Arkansas
Fayetteville, AR

Team MANURE
Making **A**merica **N**atural **U**sing **R**enewable **E**nergy

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Spring 2007

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EXECUTIVE SUMMARY

The United States is facing increasing pressure to find renewable energy sources due to rising energy costs. With world energy demand at an all time high, renewable energy has been thrust into the forefront of research as a means to mitigate this looming crisis. Throughout the United States, there is a large quantity of agricultural biomass that could be used to generate energy and lessen the dependence on diminishing resources. Specifically, animal feeding operations (AFOs) such as dairies generate large amounts of cow manure, which, when improperly handled, causes both air and water pollution. Currently, most manure is temporarily stockpiled and used as a fertilizer. Methane, a greenhouse gas, is emitted from these large piles and water pollution occurs from runoff as manure is field applied. This creates a huge pollution problem, but also presents an attractive opportunity.

Several technologies were considered as options for converting this agricultural biomass into useful forms of energy. Fixed bed gasification was chosen as the most viable solution. It was chosen in lieu of competing technologies because of its ability to handle various feeds, but also because large amounts of relatively dry manure are stockpiled in the arid environment of the Southwest. The hot, dry climate creates low moisture content (~ 20%) manure that can be effectively utilized in a gasification process. Team MANURE has designed a gasification power generation unit that processes this manure as well as various other agricultural biomass including nursery tree trimmings.

New Mexico has one of the largest dairy cow populations in the nation. It is home to about 340,000 cows which generate approximately seven and a half million tons of manure (wet basis) each year. This manure has the potential, at 20% efficiency, to generate ~85 MW of electricity.

The gasification unit was designed so that it could be implemented in rural settings. The average size of dairy farms in New Mexico is around 2,000 cows, with larger dairies having around 3,000 cows each. The Team MANURE gasification system was designed to handle the manure from two adjacent dairies with 6,000 cows total. A demographic study of the New Mexico dairy industry indicates that this is a feasible situation.

The gasifier facility converts the biomass into electricity and process heat. Two MW of electricity is produced by a steam boiler/turbine generator unit. This electricity powers both of the dairy farms and the excess electricity is sold into the power grid. This process also produces

about 3.5 MW of low level energy, at about 250 °F, which provides all of the heating requirements for the two dairies and offers the opportunity to export excess heat. This low level energy can be in the form of low pressure (approximately 15 psig) steam or hot water which can be utilized in many manufacturing facilities or residential settings.

An economic analysis of the process was conducted. The total capital investment is $3.0 million with yearly operating costs of $774,000. Utilities are required to have 6% (in 2007) annual retail energy sales from renewable energy. Renewable energy generated within New Mexico is given preference, other factors being equal. The utilities are also required to offer a ‘green’ pricing option for customers and develop a program to communicate the benefits and availability of this option. The mandated price paid by utilities for renewable energy is $0.063/kWh for biomass projects according to the New Mexico Reasonable Cost Threshold for renewable energy established by the New Mexico Public Regulation Commission. Companion projects which utilize low level energy will improve the economics of Team MANURE’s project significantly. With a suitable companion project which pays natural gas prices ($3.50/MMBtu) for the 3.5 MW of low level energy, the project economics are: capital cost of $3.0 million, yearly operating cost of $775,000, and for a ten year project with a tax rate of 36%, the net present worth is $1 million, the IRR is 18%, and the payout period is 3.5 years.

BACKGROUND

According to the Environmental Protection Agency, forty percent of America's waterways still remain too polluted for fishing and swimming despite tremendous progress since Congress passed the Clean Water Act[1]. Animal Feeding Operations (AFOs), such as dairies are a major contributor to this pollution. Waste from AFOs continues to degrade our nation's waters, threaten drinking water, and pollute the air[1]. "*Animal waste has the potential to contribute pollutants such as nutrients (e.g., nitrate, phosphorous), organic matter, sediments, pathogens (e.g., giardia, cryptosporidium), heavy metals, hormones, antibiotics and ammonia to the waters we use for drinking, swimming and fishing*.[2]" AFOs are also a contributor to significant air pollution problems such as dust, smog, greenhouse gases, and odors[2].

A single dairy cow produces about 120 pounds of wet (23 lb dry) manure every day[3], which, if mismanaged, has the potential to cause significant pollution problems. However, if this manure is handled properly it is a valuable biomass resource. Biomass is the nation's largest renewable energy source. In 2002, 86% of the energy consumed in the United States was supplied by nonrenewable fossil fuels[4]. Biomass offers a sustainable alternative to conventional energy sources and provides many benefits such as national energy security, rural economic growth, and environmental benefits[5].

New Mexico is one of the nation's largest milk producing states providing 4% of the 177 billion pounds of milk produced annually in the United States and is ranked seventh in the nation in terms of its dairy cow population, with about 340,000 cows[6]. New Mexico also ranks first in the nation in dairy farm size, with an average herd size of about 2,000 adult cows per farm[5]. Therefore, the premise of this study is the utilization of the biomass resources in New Mexico, specifically the large amounts of diary manure.

TECHNOLOGY EVALUATION

There are many different technologies that can be used to convert biomass into a useful form of energy. Several factors were considered in determining the most appropriate technical solution to the cow manure utilization problem. Each technology was evaluated with regard to the properties of feedstock needed, usefulness of products produced, economic feasibility, and ease of operation and maintenance. The following technologies, which are described below and summarized in Table 2, were considered as possible solutions to the problem: anaerobic digestion, hydrolysis/fermentation, pyrolysis, gasification, and co-firing.

Anaerobic Digestion

Anaerobic Digestion is a biological process that converts organic material under oxygen-starved conditions into a gas principally composed of methane and carbon dioxide. The process of anaerobic digestion occurs in three steps: hydrolysis, acid formation, and methane production. During hydrolysis, bacterial enzymes break down the organic material into simple sugars. The sugars are then converted to acetic acid, carbon dioxide, and hydrogen. Subsequently, the bacteria convert the acetic acid to methane and carbon dioxide and combine carbon dioxide and hydrogen to produce methane and water[7]. The following four digester designs are currently used to digest dairy manure: covered lagoon, complete-mix, plug-flow, and fixed-film[8]. Table 1 summarizes the pertinent characteristics of these digester designs. This technology is primarily used for wet dairy manure, and would require unreasonable amounts of water to be applied to the dried waste stream specified for the WERC problem.

Table 1. Types of Anaerobic Digesters[8]

Digester Type	**Description**	**Total Solids**	**Hydraulic Retention time (days)**	**Temperature**
Covered Lagoon	Impoundments with a gas-tight cover installed to capture the biogas.	< 2 %	35-60	Ambient
Fixed-film	Bacteria are immobilized on a packing material within the reactor vessel.	< 2 %	2-4	Ambient/ Mesophilic
Complete-mix	CSTR's where the digester contents are mixed by mechanical agitation, or effluent or biogas recirculation.	3-10 %	20-25	Mesophilic
Plug-flow	Unmixed systems where waste flows as a plug through a horizontal reactor.	10-14 %	20-30	Mesophilic

Hydrolysis/Fermentation

Hydrolysis/Fermentation is a biomass to energy process that involves the hydrolysis of cellulose into glucose. The glucose is then fed to a fermenter where it is converted into ethanol by microorganisms. A "pretreatment" is often employed as a means to expose the cellulose by separating it from hemicelluloses and lignin[9]. The following pretreatment techniques are currently being used and/or developed: concentrated acid, high temperature/dilute acid, and clean fractionation. However, these pretreatment techniques are not cost effective[10]. Also, the second hydrolysis step, which is normally accomplished by using an enzyme catalyst, is too costly. It is estimated that for this entire process to be economically viable, the cost of producing the enzymes needs to be reduced by a factor of ten[11].

Pyrolysis

Pyrolysis, another biomass to energy technology option, involves heating the biomass in an anaerobic environment to produce primarily liquid hydrocarbons called pyrolysis oil or bio-oil. The bio-oil produced by biomass pyrolysis is a dark brown liquid which has a heating value about one-half that of conventional fuel oil[12]. Pyrolysis is typically performed under pressure and at operating temperatures above 750 °F. Also, pyrolysis requires drying of feed material to less than 10% moisture, and the feed must also be ground to small particle sizes. The product liquids from pyrolysis contain significant amounts of organic acids, precluding their use as fuel for internal combustion engines. Conversion of pyrolysis oils to bio-fuels or chemicals for industrial applications requires hydrogenation of these organic acids. Hydrotreating pyrolysis oil consumes large amounts of hydrogen, limiting economic feasibility.

Coal Cofiring

Cofiring is another option for converting biomass to electricity by adding biomass as a partial substitute fuel in existing coal-fired boilers[13]. The biomass, which can be substituted for up to 20% of the coal used in the boiler, is combusted with the coal. By using biomass as a substitute fuel, nitrogen oxide, sulfur oxide, and greenhouse gas emissions will all be reduced[14]. The most significant disadvantage of this technology is the transportation costs of moving the biomass from the farm to a coal fired power plant.

Biomass gasification

Biomass gasification is the process of converting solid biomass into a gaseous fuel. The fuel gas produced by gasification has a heating value ranging from 10 to 50% of the heating value of natural gas. Gasification is probably the most flexible biomass to energy technology as the fuel gas produced can be used directly as a fuel for heating applications, used for the production of electricity, or used as a synthesis gas for the production of liquid fuels, chemicals, or hydrogen[12]. Also, gasification systems are able to handle mixed feedstocks as long as the feedstocks have a moisture content of less than 30%[7]. Two main types of reactors used for biomass gasification are fixed bed and fluidized bed. In a fixed bed gasifier, the incoming biomass is moved as a pile through a chamber where the biomass is reacted with an oxidant to heat the biomass to an appropriate temperature to produce synthesis gases. In a fluidized bed reactor, biomass particles are fluidized in a bed of inert material (typically sand).

Table 2. Summary of Biomass to Energy Technologies

Technology	**Advantages**	**Disadvantages**
Anaerobic Digestion	-Reduces odors -Reduces pathogens	-Feedstock needs to be wet -Cannot handle mixed feedstocks
Hydrolysis/Fermentation	-Produces Ethanol	-Not economical -Manure has never been used as a feedstock.
Pyrolysis	-Can handle mixed feedstocks	-Requires less than 10% moisture content feedstock
Fixed Bed Gasification	-Can handle mixed feedstocks -Easier to operate than fluidized bed reactors -Many uses for product gas	-Requires large local feedstock availability
Fluidized Bed Gasification	-Can handle mixed feedstocks -Many uses for product gases	-Requires large local feedstock availability -Difficult to operate
Cofiring	-Reduces sulfur oxide emissions -Reduces nitrogen oxide emissions -Avoidance of landfills	-Can only be applied at facilities with existing coal-fired boilers.

Fixed bed gasification was selected as the best solution for the current task for the following reasons:

1. Gasification is able to handle mixed feedstocks.
2. Gasification will handle 20% moist manure; whereas, anaerobic digestion will not.
3. Fixed bed gasification is practical to operate on a dairy farm, whereas fluidized bed gasification is not.

BENCH SCALE DESIGN AND OPERATION

The bench scale gasifier was designed to demonstrate efficient production of energy (in the form of hot, combusted gas) and to demonstrate that partially dry cow manure can be successfully gasified in a relatively simple gasifier. The bench scale gasifier was also designed to handle a mixture of partially dry manure and tree trimmings. A process flow diagram of the bench scale unit is shown in Figure 1, and the stream attributes table for the bench scale is included as Table 3, below. The bench scale steam attributes table is based on calculated estimates, not on experimental data.

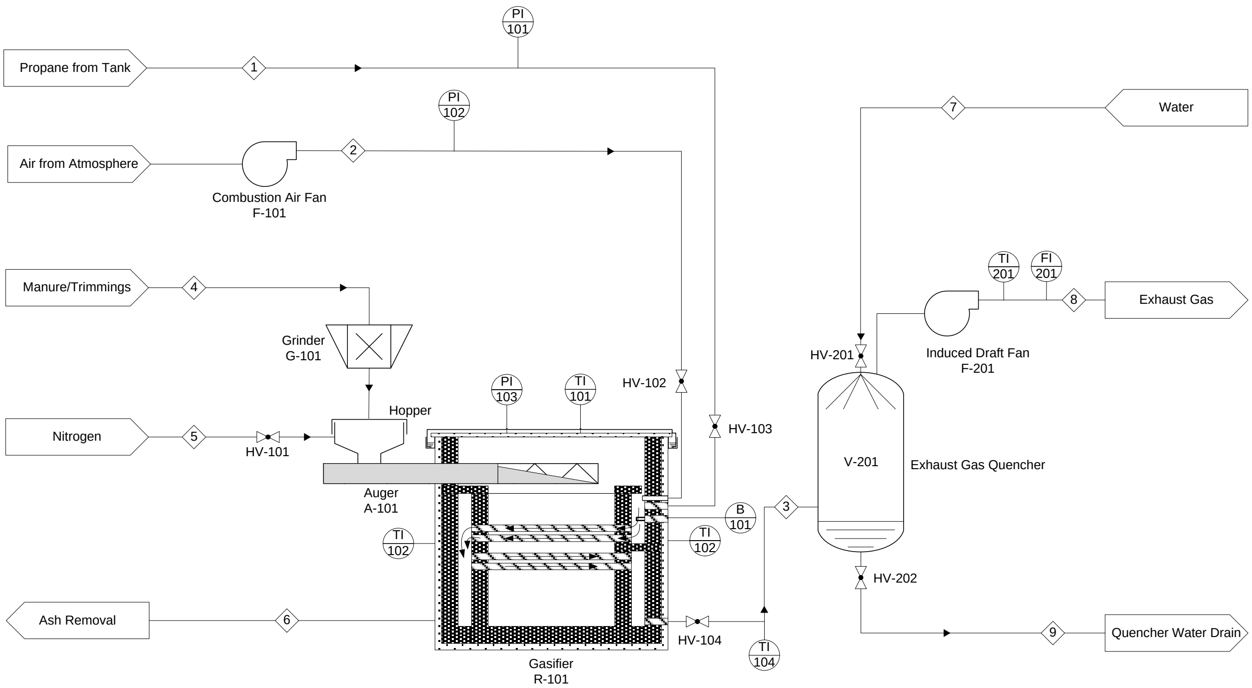

Figure 1. Process Flow Diagram for Team MANURE's Bench Scale Gasification Unit

Table 3. Bench Scale Stream Attributes Table

Stream#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Manure Solids (lb/hr)	0	0	0	24	0	11.7	0	0	0
O_2 (lb/hr)	0	52	30.5	0	0	0	0	30.5	0
CO_2 (lb/hr)	0	0	21.2	0	0	0	0	21.2	0
H_2O (lb/hr)	0	0	18.1	6	0	0	120	138	0
N_2 (lb/hr)	0	176	176	0	0.024	0	0	176	0
Propane (lb/hr)	6.67	0	0	0	0	0	0	0	0
Total Flow (lb/hr)	6.67	227.1	245.4	30	0.024	11.7	120	365	0
Cr (ppm)	0	0	0	2.1	0	4.3	0	0	0
Volumetric Flow Rate (cfm)	1.02	49.4	200	0.017	0.0056	x	x	105	x
Temperature (°F)	70	70	1472	70	70	70	70	212	212
Pressure (atm)	1 atm	1 atm	-1" WC	1 atm	2" WC	1 atm	1 atm	1 atm	1 atm
Stream 9 is equal to any excess quenching water fed in.									

The bench scale gasifier will be fed from a 1 ft^3 feed hopper, which will be purged with nitrogen. The lid of the hopper will be sealed with a gasket. A 1 ½" diameter 316 stainless steel auger (A-101) feeds the manure and tree trimmings into the gasifier. Prior to introduction into the auger the manure and tree trimmings will be ground to pass ¼” sieve. The feed entering the gasifier (R-101) will be distributed over a heated bank of tubes (1” OD, 7/8” ID, 4 horizontal rows with 6, 5, 6 and 5 – 22 total - from top to bottom, in a staggered arrangement) as it is showered from the sloped feed tube. Figure 4 shows the first row of tubes. The gasification occurs in an oxygen deficient environment at ~ 1470 ^{o}F. The feed-filled auger, and a slight vacuum within the pyrolysis zone will prevent backflow of gases from the pyrolysis zone.

Propane will be used to start-up the bench scale unit. The propane will mix with air below the combustion air inlet distributor and be lit by a hot surface igniter. These hot gases will then be pulled through the tube banks, by the induced draft fan (F-201), which will heat the tubes during start-up. After the gasifier is heated to about 1470 ºF, the propane flow will slowly be reduced as manure is fed to the gasifier and pyrolysis gases are produced in quantities sufficient to sustain the combustion. Also, during start-up, six 700 W strip heaters (see Figure 3) will be used to reduce start-up time to achiever operating temperature.

A slight negative pressure (about 1-2” water column) will be maintained on the inner chamber of the gasifier so that the pyrolysis gases are pulled from the pyrolysis chamber into the combustion chamber. A forced draft fan will provide the pressure to force the combustion air through the air inlet pipe and the combustion air distributor. A water manometer on the discharge of the forced draft inlet fan will be used to measure the flow rate of combustion air through the inlet pipe and the perforated combustion air distributor. Thermocouples will be used to measure the following temperatures: combustion air, gasification chamber, combustion chamber, water scrubber inlet, and water scrubber outlet. The exhaust gas will enter a quencher (V-201) where the gases are cooled before they enter the induced draft fan (F-201).

Safety was paramount to the design of the bench scale. After the initial drawings for the project, the team discussed modifications and precautions which needed to be implemented to increase safety. The design was altered to incorporate these measures. Then, a safety audit by several faculty and staff, which included the safety coordinator and a professor of process chemical safety from the Chemical Engineering department, was conducted. The design and operating procedures were reviewed by this group, and the process design was once again changed to incorporate the recommended changes. The most important changes in the safety review were the elimination of a compressed air cylinder for feeding the combustion air and the addition of a water sealed lid.

There is a 3” water seal around the lipped lid of the gasifier. This seals the gasification chamber from the atmosphere, preventing introduction of excess oxygen, which could result in uncontrolled combustion. The water seal allows the gasifier lid to lift easily in case combustion occurs in the pyrolysis chamber. Also, shields are erected around the apparatus for safety. They are constructed of cement board on the sides facing the gasifier nailed to 2x4 studs and by ½” plywood on the outside.

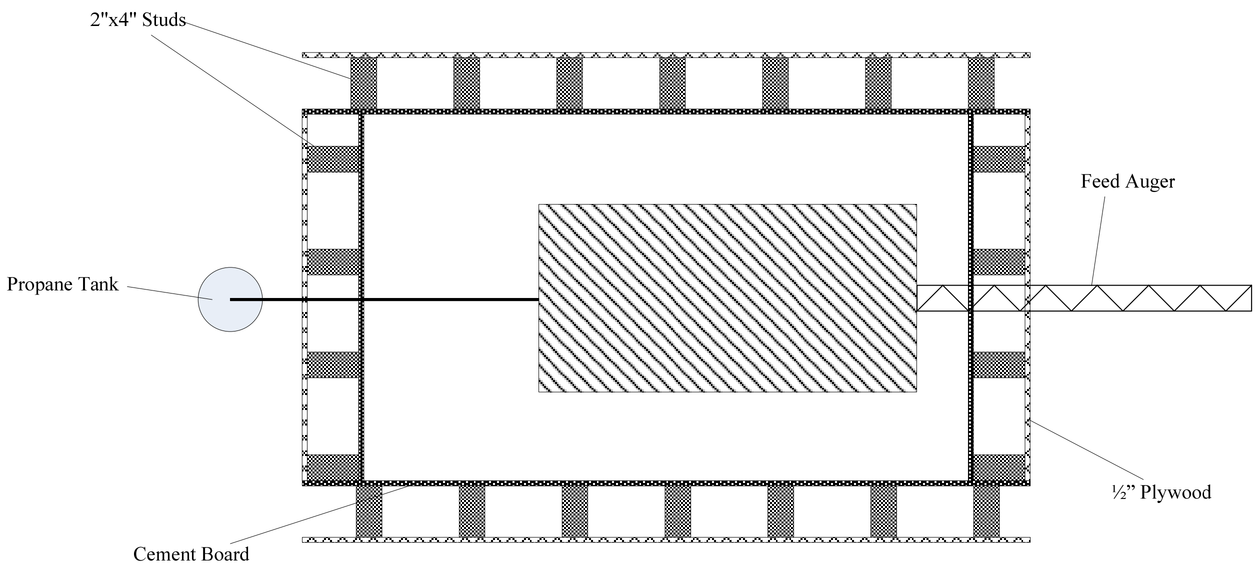

Figure 2. Safety Shield Schematic (Top View)

At the completion of this report, the bench scale unit was still under construction. However, the design has been finalized and will be constructed accordingly. Test results and analysis will be available at the competition. Photographs are presented below which present under construction views of the gasifier.


Figure 3. Strip Heaters for Start-Up


Figure 4. A Tube Bank within Gasifier

FULL-SCALE DESIGN

There are several aspects that differ between the bench and full scale designs. There is a bank of tubes in the bench scale unit which provides ample heat transfer area. In the full scale unit, a portion of the combustion air will be fed through the gasifier floor into the bed of solids to provide sufficient combustion to heat the bed to the pyrolysis temperature of 1470 °F. Another difference is ash removal. In the bench scale, the ash will be removed after the unit is shut down and allowed to cool. A few bricks will be removed from the side walls, and the ash raked from the gasifier. In the full scale unit, the ash is collected in a bin at the end of the gasifier and is augered from the gasifier. The exhaust gas is water quenched and then vented through the induced draft blower in the bench scale. However, in the full scale plant unit, the gas will be utilized in a boiler and a feed dryer.

With the premise of 3,000 head of dairy cows on each of two adjacent farms, this facility handles the partially dried manure from 6,000 cows. At 23 pounds of dry solids manure produced per cow per day with 20% moisture, the total manure feed is 173,000 lb/day of manure (138,000 lb/day of dry solids). Many farmers stockpile their manure in the dry arid climate of New Mexico; consequently manure piles are available at 20% moisture. One worker on each dairy farm for two shifts per day will use a 35 ft^3 front-end loader to move the manure from the barnyard piles into a low profile roto grinder that can handle 300 ft^3/hr. The manure is ground into ½" particles that are blown out the exit chute of the grinder into the open end of an 8x9x40 ft walking floor trailer. The capacity of the trailer at 30 lb/ft^3 of manure is 85,000 lb. The trailers will not be totally filled. Three partially filled trailers per day will feed this facility.

The live floor trailers are used to feed the manure into the feed hopper at the plant. Thus, two of these trailers are normally at the plant site, two are being loaded at the farm sites, and there is one spare for a total of five live bottom feed trailers. The feed leaves the live floor trailers and enters an 8x10 ft augered feed hopper at a constant rate of 7,200 lb/hr. The manure will be fed and mixed with the ground tree trimmings at this point by feeding manure from a live bottom trailer on one side of the augered hopper and by feeding tree trimmings from another live bottom trailer on the other side of the hopper.

The feed is augered from the feed hopper into a rotary dryer which contacts the feed with 800 ºF hot gases from the boiler, which cool to 400 °F within the dryer. From the dryer, the feed drops into an augered feed bin, which feeds the pyrolysis unit. Three 2' diameter augers convey the dry feed into the gasifier at three locations across the entrance of the gasifier, at a feed rate of 240 ft^3/hr.

The gasification unit will be a fixed-bed firebrick lined gasifier. It will be designed to accept feed through three feed screws and have combustion air entering through a grated floor. The floor will be on a slight incline, from feed to ash exit. The augered feed will push the gasifying bed down the inclined floor to the ash exit. The first one third of the floor will be constructed of slotted 310 stainless steel. Forty percent of the combustion air is fed through the slotted stainless steel floor in order to gasify the bed to a temperature of 1470 °F. The raised slots for the combustion air entry will extend up and over the floor down past the slot to prevent the feed from clogging the slots. The moving gasifying bed will push the ash into an augered chamber at the end of the gasifier, which will remove the ash from the gasifier.

The product gases exiting the gasifier enter a boiler where they are mixed with the remaining combustion air and burned at a temperature of about 3200 °F. The autoignition temperature for these gases is about 1000 °F, and the flame temperature is well above this autoignition temperature. The hot combustion gases produce 25,000 lb/hr of steam at 600 psig and superheated to 1000 °F, giving a boiler duty of 26 MMBtu/hr. The boiler package includes a combustion air blower and an induced draft blower to provide the necessary gas flow through the boiler and downstream equipment. The steam from the boiler enters a steam turbine which drives a 2 MW electric generator. The steam turbine exhausts steam at about 15 psig (250 °F) which is then used as an energy source for the on-site dairies and local companion industries.

The 800°F gases exiting the boiler enter a rotary tumble dryer where the feed is dried to 5% moisture content and heated to 400°F. The moist gases from the feed dryer then enter a 6' diameter by 30' tall limestone scrubber which will remove any solids, scrub the SO_2 to below 5 ppm, and cool the gases to 150°F. The scrubber slurry, containing about 10 wt % solids will be recirculated from the sump of the scrubber to the top of the tower by a 500 gpm centrifugal pump. The byproduct $CaSO_4$ will be filtered from the circulating slurry in a 3' wide by 5' diameter rotary vacuum filter. The filtrate from the vacuum filter will gravity flow back to the scrubber tower sump. 36 lb/hr of SO_2 enters the scrubber and < 1 lb/hr of SO_2 exits the scrubber. 75 lb/hr of $CaSO_4$ is produced and, with the water of hydration, the total amount of solids to be land filled is about 2,300 lb/day. At $100 per ton bulk land fill cost, the yearly expense will be about $40,000.

The biomass produces about 0.3 lb CO, 0.023 lb H_2, and 0.086 lb CH_4 with a basis of 1 lb feed at 20% moisture. It produces a syngas with a heating value of ~ 5400 BTU/lb feed.

The process flow diagram for the Team MANURE process is presented in Figure 5, and its stream attributes are given in Table 4.

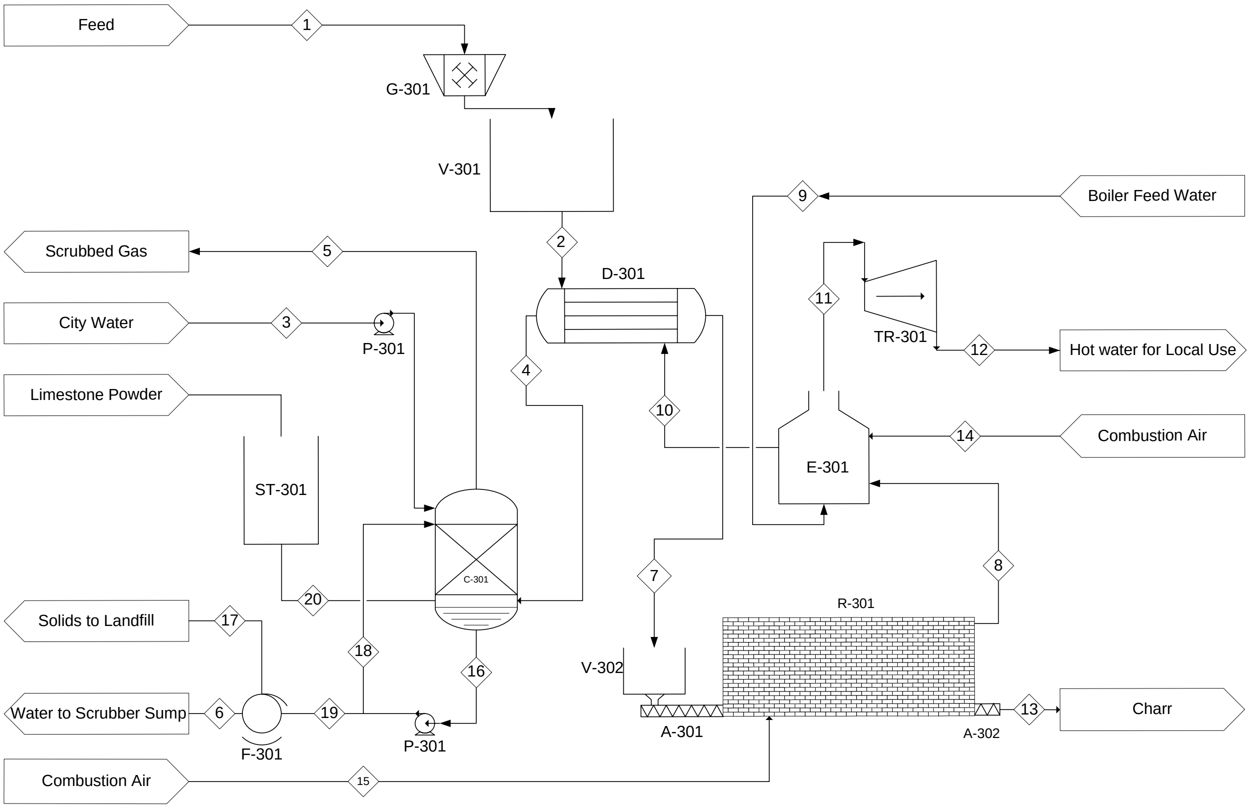

Figure 5. Full Scale Process Flow Diagram

Table 4. Plant Unit Stream Attributes Table

Stream#	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Biomass lb/hr	5,760	5,760	0	0	0	0	5,760	0	0	0	0	0	2,813	0	0	0	0	0	0	0
CO lb/hr	0	0	0	0	0	0	0	1,297	0	0	0	0	0	0	0	0	0	0	0	0
H_2 lb/hr	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
CH_4 lb/hr	0	0	0	0	0	0	0	417	0	0	0	0	0	0	0	0	0	0	0	0
O_2 lb/hr	0	0	0	2,014	2,014	0	0	0	0	2,014	0	0	0	5,842	2,014	0	0	0	0	0
CO_2 lb/hr	0	0	0	5,097	5,097	0	0	2,039	0	5,097	0	0	0	0	0	0	0	0	0	0
H_2O lb/hr	1,440	1,440	857	4,324	5,132	670	360	1,513	25,500	3,244	25,500	25,500	0	0	0	200,000	23	199,307	693	0
N_2 lb/hr	0	0	0	25,859	25,859	0	0	6,631	0	25,859	0	0	0	19,228	6,631	0	0	0	0	0
SO_2 lb/hr	0	0	0	36	0	0	0	15	0	36	0	0	0	0	0	0	0	0	0	0
$CaSO_4$ lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20,000	77	0	77	0
Limestone lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	0	0	0	83
Total Flow lb/hr	7,200	7,200	857	37,330	38,102	670	6,120	12,012	25,500	36,250	25,500	25,500	2,813	25,070	8,645	220,041	100	199,307	770	83
Cr (ppm)	2.1	2.1	0	0	0	0	2.1	0	0	0	0	0	4.3	0	0	0	0	0	0	0
Volumetric Flow Rate (cfm)	x	x	x	11,595	10,315	x	x	11,507	x	19,658	616	x	x	6,764	1,922	x	x	x	x	x
T (°F)	70	70	70	250	150	150	400	1472	70	800	1000	250	1472	70	70	150	80	150	150	70
P (atm)	1	1	1	1	1	1	1	1	1	1	40.8	2	1	1	1	1	1	1	1	1

REGULATORY ANALYSIS

The process of generating energy from manure and tree trimmings should be performed in a manner that does not harm the environment. The Environmental Protection Agency (EPA) and the New Mexico Environmental Department (NMED) implement the federal and state environmental standards and regulations that govern the construction and operation of this plant. The major regulations are presented in Table 5 below.

Environmental

After an environmental review conducted by the EPA, the plant will either be required to submit an Environmental Impact Statement (EIS), or have no significant impacts on the environment, be issued a FNSI (Finding of no significant impact), and an EIS will not be required (40 CFR 1501.4). The main environmental impact that would concern the EPA is the air emissions. The plant has the potential to produce of total suspended particulates, sulfur compounds (SO_2, H_2S, and total reduced sulfur), carbon monoxide, and nitrogen oxides in the ambient air. The main concerns are SO_x emissions which need to be below 0.16 lbs/MMBtu. A scrubber has been designed so that emissions will be under the regulated limits. According to findings in literature and our gas scrubbing and design, none of these pollutants should be near regulated limits and a FNSI is expected to be issued[15].

Dairy farms are already required to have both a National Pollutant Discharge Elimination System (NPDES) Permit and a Discharge Permit (DP). The NPDES permit is issued by the EPA under the authority of the Clean Water Act. The DP is issued by the NMED under the authority of the New Mexico Water Quality Act. The NPDES permit is intended to protect surface water quality, while the DP is to primarily protect ground water quality, but also surface water[16]. The NPDES permit for the farms would not need to be modified under current regulations, but a modification of the Nutrient Management Plan (NMP) will be required[17]. The NMP addresses handling, storage and land application of manure and wastewater, among other things for AFOs. A Discharge Permit will be also need to be obtained[18].

The gasification process does not require an operating permit from the state, because the plant is not a major pollution source and air emissions are not expected to exceed De Minimis levels. The operating permit may be obtained if desired. A construction permit must be obtained prior to commencing construction. Once obtained, all construction must comply with NMAC building codes[18].

A product of the gasification process is ash that will be used as fertilizer. This ash will not contain any regulated pollutants. To ensure that the ash will not be an environmental hazard, a Toxic Characteristic Leaching Procedure Test will be performed[15].

Renewable Energy Requirements

Each public electric utility is required by the Renewable Portfolio Standard (RPS) to develop a reasonable cost renewable energy portfolio. Renewable energy generated within New Mexico is given preference, other factors being equal. Utilities are required to have 6% (in 2007) annual retail energy sales from renewable energy. The percentage increases by 1% until it reaches 10% in 2011. Compliance with the RPS is verified by the use of renewable energy credits (RECs). One kWh of electricity generated by biomass is worth two kWh toward the RPS. A reasonable cost threshold is also set so that the utility does not have to pay over a certain price for its renewable energy. The utilities are also required to offer a green pricing option for customers and develop a program to communicate the benefits and availability of this option[19].

Table 5. Major Federal and State Regulations[15,18]

Concerns	Regulations	Description
Air Quality	40 CFR 50 (National Ambient Air Quality Standards)	Sets maximum allowable concentrations of total suspended particulate, sulfur compounds, carbon monoxide, and nitrogen dioxide
	20 NMAC 2.3	New Mexico ambient air quality standards
Water Quality	40 CFR 122	National Pollutant Discharge Elimination System Permit Program
	40 CFR 131	National Water Quality Standards
	40 CFR 430	Pretreatment Regulations for New Sources of Pollution
	20 NMAC 6.2	Ground and Surface Water Protection
	20 NMAC 6.4	Standards for designated uses of surface waters
Gasification Plant	20 NMAC 2.43	New Mexico Administrative Code for gasification plant operation
	20 NMAC 2.7	Excess emissions during malfunction, startup, shutdown, or scheduled maintenance
	17 NMAC 9.570	Governs Small Power Production
	17 NMAC 9.572	Renewable Energy for Electric Utilities
Worker Safety	29 CFR 1,2	Labor practice regulations
	29 CFR 1910	National Occupational Safety and Health Standards
	11 NMAC 1	General Labor provisions
	11 NMAC 5.1	State Occupational Safety and Health Standards
Construction	29 CFR 1926	Safety and Health regulations for construction
	11 NMAC 5.3	OSHA standards for construction
	14 NMAC 7.2	Regulations for Building Codes
	20 NMAC 2.72	Construction Permits

HEALTH AND SAFETY

The Occupational Health and Safety Administration (29 CFR 1910.132) regulates the general requirements for proper protective equipment (PPE). All protective equipment for eyes, head, and extremities shall be provided for operators. Operators will be required to wear hard hats, safety goggles, steel toed boots, hearing protection as required, and gloves while operating equipment. To comply with the regulations, all provided PPE will be used and maintained in a sanitary and reliable condition wherever necessary due to operating conditions. All operators will be trained of when, why, and how to use all PPE. Operators will also receive training for CPR, first aid, and fire extinguisher use. All training will be performed by a qualified safety officer[15].

COMMUNITY RELATIONS

The community will be informed of the environmental effects of manure gasification, ensuring that they are aware of environmental benefits of the project, including the creation of an alternative energy source, environmentally friendly disposal of excessive manure waste, and the elimination of soil leaching and runoff contaminants resulting from bulk manure stock-piling. The EPA is required to have the FNSI available to affected and/or interested public. The residents of the community will be provided with non-proprietary information regarding chemical use and emission. The gasification plant operators will maintain an archive of comprehensive, up-to-date Material Safety Data Sheets (MSDS) at the process site, as well as safety guidelines and emergency contact information.

In accordance with the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA), toxic or hazardous chemicals present in amounts meeting or exceeding the regulated threshold will be reported to the community[20]. Information regarding process safety and emergency procedures will be provided to local emergency response units to ensure efficient and appropriate response in the event of an accident.

A community meeting will be held to inform the public of the environmental and economic impacts of the plant, at which the public will be able ask questions and voice concerns. The main focus of these meetings will be to communicate the benefits and availability of the electricity generated from manure. The public electric utilities are also required to offer a green pricing option for customers and develop a program to communicate the benefits and availability of this option.

ECONOMIC ANALYSIS

An economic analysis of the process was conducted and a summary of the costs are outlined in the table below.

Table 6. Economic Analysis of Gasification Plant

	Cost Estimation Basis	Purchased Cost
	Equipment Costs	
Prep Equipment		
Chippers (2 total)	Web	*$ 36,000*
Front End Loader (2 total)	Web	*$ 114,000*
Live Bottom Trailer(5 total)	Web	*$ 259,000*
Subtotal		*$409,000*
Process Equipment		
Gasifier (1 total)	Furnace cost, P&T	*$ 100,000*
Dryers (1 total)	Web	*$ 42,000*
Steam Boiler (1 total)	Web	*$ 150,000*
Conveyor/Hopper (2 total)	Web	*$ 56,000*
Steam Turbine (1 total)	Web	*$ 85,000*
Gas Scrubber (1 total)	Web	*$45,000*
Generator (1 total)	Web	*$75,000*
Vacuum Filter (1 total)	P&T	*$50,000*
Pumps (2 total)	P&T	*$4,000*
Limestone Storage Tank (1 total)	P&T	*$5,000*
Subtotal		*$612,000*
Total Equipment Costs		*$ 1,021,000*
Construction and Installation		
Equipment Installation	200% of Process Equipment Cost	*$1,226,000*
Construction Expense	100% of Process Equipment Cost	*$612,000*
Subtotal		*$1,838,000*
Fixed Capital Investment		*$2,860,000*
Working Capital	15% of Fixed Capital Investment	*$153,000*
Total Capital Investment		***$3,013,000***
	Yearly Costs	
Labor Costs	$50,000/person/year with 7 workers	*$ 350,000*
Operation and Maintenance		
Maintenance & Repairs	6% of Fixed Capital Investment	*$172,000*
Operating Supplies	15% of Maintenance & Repairs	*$26,000*
Utilities	5% of Fixed Capital Investment	*$143,000*
Local Taxes & Insurance	1% of Fixed Capital Investment	*$29,000*
Limestone		*$15,000*
Land Filling		*$40,000*
Subtotal		*$425,000*
Total Yearly Costs		***$775,000***

The total capital investment is $3.0 million for the gasification plant. The electricity capacity was determined based on electrical energy produced by wood fired power plants; in particular information was used from the McNeil Power Station in Vermont: *"To run McNeil at full load, approximately 76 tons of whole-tree chips are consumed per hour. At full load, the plant can generate 50 megawatts (MW) of electricity."* The heating value of dry manure is approximately equal to the heating value of the scrub trees and limbs and tree tops used as fuel for the McNeil plant[23]. At 138,000 lb/day (2.875 tons/hr) the current facility will produce 4% of the electricity produced by the McNeil facility for a total of 2 MW of electricity. At $0.063/kWh for electricity supplied to the grid the yearly benefits for electric sales is $1.04 million/yr. Also, the project economics is premised upon selling the residual energy (47% of the manure heating value is sold) in the steam turbine exhaust to local industry at natural gas cost of $3.50/MMBtu, for yearly sales of $442,000.

Using an income tax rate of 36%, a yearly income of $1.48 million, yearly operating costs of $775,000 the interest rate of return (IRR) is 14%. And, with net income of $705,000 and a capital cost of $3.0 million, the payout is about 3.5 years.

There are a number of tax credits that apply to the process. The Renewable Electricity Production Tax Credit is a corporate tax credit for electricity generated by qualified energy resources. Open-loop biomass receives $0.01/kWh for up to five years ($175,000 per yr). The Biomass Equipment and Materials Deduction allows the deduction of the value of biomass equipment and materials used for processing biopower in determining the amount of compensating tax due. The compensating tax is 5% of the value of the property, and the deduction is similar to a sales tax exemption. The IRR accounting for the Renewable Electricity Production Tax Credit is 18%.

CONCLUSIONS

Team MANURE concludes that a biomass gasification plant is the most viable way to dispose of manure, decrease pollution, and generate renewable energy. A gasification facility, which can be located between two dairy farms, will create both electricity and low level energy which can be used on site, as well as sold to local industries. This design is economically feasible with a net income of $705,000 and IRR of 18%.

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March 7, 2007

Melissa Buckmaster
University of Arkansas Task 4 Team

Dear Melissa:

Thank you for allowing me to review your project, "Conversion of Biomass Resource to Useful Forms of Energy and Other Products." I enjoyed the report and I think it demonstrates the viability of using manure and tree trimmings as a renewable energy resource. Below are some comments regarding the health and legal issues in your report.

1. Although you mention that air and water pollutants will be minimal, you should probably state what the pollutants will be and their amounts for converting 138,000 lbs of dry manure per day. In particular, what will be the fate of NO_x in the scrubbed gas and phosphates in the drain water?

2. Under "Health and Safety" it states that operators will be trained in the use of PPE but does not mention who will do the training. You might point out that training will be performed by a qualified safety officer.

3. As an added precaution in both your bench scale and full scale designs, I suggest you install sufficient check valves to prevent the possibility of gas backflow.

Your team has obviously been very thorough in putting together this project and I hope this review is helpful. I wish you the best of luck in the competition.

Sincerely,

Glen Akridge, Ph.D.
Laboratory & Safety Manager

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March 8, 2007

Task 4 Team
University of Arkansas
Bell Engineering Center
Fayetteville, AR 72701

Dear Task 4 Team:

I have read your report on the "Conversion of Biomass Resource to Useful Forms of Energy and Other Products." I was impressed with your technology evaluation and agree with your choice for the fixed bed gasification process. It provides a relatively less complicated design that is practical for use in a large dairy operation.

You have requested that I review the Health and Legal Issues associated with your design project. Your focus on the Federal and State regulations cover all of the immediate concerns that would affect construction, startup and operations. It was properly investigated and well presented.

I think that it would be beneficial to have a personnel safety plan developed for any potential operational failures, procedures for emergency shut down, as well as possible alternate means of ash disposal. There is also the possibility of tar condensation and soot formation in your exhaust gas quencher that would necessarily contact your waste water stream. Waste water disposal should also be addressed.

Sincerely,

Sean Slape
Plant Manager
Bioengineering Resources Inc.

March 12, 2007

Melissa,

Sorry, I seem to have run out of time.

In addition to the comments below:

- Capital cost is too low by at least a factor of 2 (probably more likely 3). I have attached a Dresser Rand Proposal for a 4 and 10 MW steam turbine and condenser as an example.

- Page 13, 800°F gases to dryer is ok, but dryer exhaust temperature usually does not exceed 200°F. Dryer duty will typically be between 1600 and 1800 Btu/lb of water evaporated.

- I don't think there is any residual energy after electrical generation. The website below has a turbine steam requirement calculator.

http://www.katmarsoftware.com/?referrer=TurbinePgm

- Something you might want to consider. Steam temperature of 1200°F exceeds present day turbine capability. Suggestion - use tmeperature below 1000°F

http://www.ms.ornl.gov/programs/energyeff/ats/highperf.htm

Wanted to get this to you now.

Kevin McQuigg
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